MANAGING PROGRAMMATIC RISK FOR COMPLEX SPACE SYSTEM DEVELOPMENTS

Peter V. Panetta
is a Senior Systems Engineer at NASA-Goddard Space Flight Center in Greenbelt, Maryland, USA. Selected as a NASA Leadership Program Fellow, he completed the System Design & Management (SDM) Program at Massachusetts Institute of Technology in June 2001. The work presented in this paper was part of his SDM master's thesis research. Prior to attending MIT, Mr. Panetta was a NASA Project Formulation Manager of constellation class missions for Earth and Space science. During the same time period, he also managed the development of micro- and nano-satellite technologies for enabling such missions. Mr. Panetta was recognized as a leader in this field, having presented papers and chaired sessions at conferences on small satellites, and co-edited a monograph. His earlier experience included working as a Senior Electronics Engineer to develop scientific instrumentation for Earth-orbiting and planetary spacecraft. Mr. Panetta also holds a bachelor's degree in Electrical Engineering from Rutgers University, a master's degree in Electrical Engineering from University of Maryland, and a master's degree in Mechanical & Aerospace Engineering from George Washington University.

Dr. Daniel Hastings
is a Professor of Aeronautics & Astronautics and Engineering Systems at the Massachusetts Institute of Technology in Cambridge, Massachusetts, USA. He is also the Associate Dean of the Engineering Systems Division.

ABSTRACT Risk management strategies have become a recent important research topic to many aerospace organizations as they prepare to develop the revolutionary complex space systems of the future. Future multi-disciplinary complex space systems will make it absolutely essential for organizations to practice a rigorous, comprehensive risk management process, emphasizing thorough systems engineering principles to succeed. Project managers must possess strong leadership skills to direct high quality, cross-disciplinary teams for successfully developing revolutionary space systems that are ever increasing in complexity. Proactive efforts to reduce or eliminate risk throughout a project's lifecycle ideally must be practiced by all technical members in the organization.

This paper discusses some of the risk management perspectives that were collected from senior managers and project managers of aerospace and aeronautical organizations by the use of interviews and surveys. Some of the programmatic risks which drive the success or failure of projects are revealed. Key findings lead to a number of insights for organizations to consider for proactively approaching the risks which face current and future complex space systems projects.

INTRODUCTION

The early identification and control of risk are critical tasks which factor heavily upon the outcomes of complex space system projects. Research was conducted to explore the perspectives of senior managers and project managers on the primary risk drivers to projects, how the project organization is addressing them, and the present ability of the workforce to perform these risk management functions. Relevant differences between the perspectives of these two management types were also evaluated to understand whether any programmatic risks could result. Since a senior manager's function is to set policies, guidelines, and provide oversight, while the working project manager carries the direct responsibility for the success or failure of a project, the comparison of viewpoints are of interest in order to gain more insight into the true risk drivers for projects.

Research data was collected by in-person interviews of senior executives, and electronic surveys sent to senior managers and project managers. Senior manager perceptions of how risk drives the projects of their organization are captured. The thoughts of project managers on what drives programmatic risk are also collected, since their perspectives come from direct experience in managing complex system development. Responses were sought from civilian government, military government, and commercial enterprises. Each of these respondents managed the development of a complex system which included one or more enabling technologies. Although the majority of respondents came from aerospace or aeronautical organizations, several respondents were managers of complex technological products for commerce. For the data presented here, 23 senior managers and 63 project managers were surveyed, and several senior executives were interviewed.

The paper begins with a discussion of the top programmatic concerns for project success by senior management. These concerns give insight to what senior managers feel is required in order to succeed with the complex system projects undertaken by their organization. Senior manager and project manager views of the strongest positive and negative impacts to a project are then discussed. These perspectives show what factors are considered to make a difference in the outcome of a project, and how much they differ in the minds of the two different management levels. Since organizations are often faced with the dilemma of finding the right project manager for a particular effort, the project manager traits preferred by senior management are presented. The types of employees involved in the identification and classification of risks, and the development of system specifications, are then explored. These findings help to reveal how well organizations are applying their personnel resources to risk management. Next, the methods by which project development teams make critical technical decisions are evaluated. The level of decision-making empowerment by the project manager and the development team, and the efficiency by which important decisions are made, have a significant effect upon the project's progress and its ability to meet its performance, cost, and schedule goals. Finally, the steps which organizations feel are necessary to prepare for successfully mitigating the risks of future multi-disciplinary complex space systems are discussed. These steps highlight where an organization's time, effort, and resources should now be invested.

DISCUSSION

Top Three Project Concerns of Senior Managers

The top three concerns of senior managers regarding project success were collected. Several themes emanated from an evaluation of this qualitative data set, as illustrated in Figure 1.

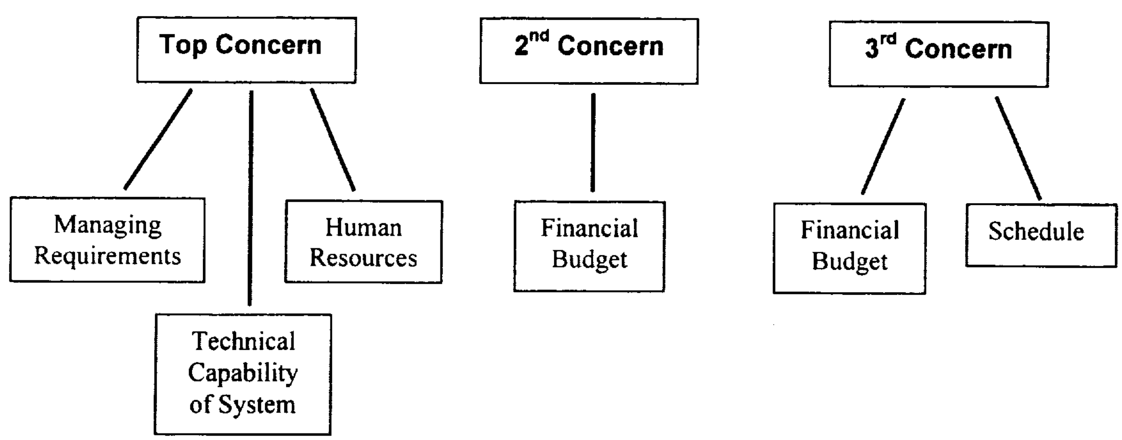

Figure 1. Top 3 Concerns for Project Success

The top concern was distributed among the categories of managing requirements, human resources, and technical capability of the system. Requirements management concerns included such things as meeting the project's success criteria, handling changing requirements, and thoroughly understanding project requirements. Human resources concerns centered around the ability of the project manager, sufficient staffing, and the quality of project teams. Concerns regarding the technical capability of the system included its successful technical performance, and operational safety. The 2nd highest concern on the minds of senior managers was primarily the financial budget. Budget aspects included realistic cost estimates, adequate budget reserves, and a balance of scope with available financial resources. The 3rd highest concern included both cost and schedule, targeting the adequacy and stability of each.

The Strongest Positive and Negative Impacts to a Project

Both senior managers and project managers were polled to determine their thoughts on what the strongest positive and strongest negative impacts are to a project. These strongest impacts are illustrated in Table 1. Each entry provides the number of instances in parentheses.

Senior Managers		Project Managers	
Strongest Positive Impact	**Strongest Negative Impact**	**Strongest Positive Impact**	**Strongest Negative Impact**
Strong Project Leadership (10)	Insufficient & Unstable Resources (6)	Team Quality & Commitment (24)	Insufficient & Unstable Resources (22)
Open, Clear Communications (4)	Poor Project Leadership (5)	Adequate & Stable Resources (6)	External Influences (12)
	Changing Requirements (3)	Strong Customer Relationship (6)	Changing Requirements (9)
		Senior Management Commitment (4)	

Table 1. Strongest Positive and Negative Impacts to a Project

The strongest positive impacts to projects perceived by senior managers are grouped into two major subject areas: Strong Project Leadership, and Open, Clear Communications. The strong project leadership theme was stated by a significant number of senior manager respondents. This theme focuses on the value for outstanding leadership qualities of the project manager, where his/her technical, managerial, and communicative abilities make the difference in successfully coordinating the project team to meet the objectives and requirements of the project. The open, clear communications theme emphasizes honest, explicit communication among all personnel involved with the project, both internal and external to the project organization. This includes clearly stating project goals, objectives, scope, and all resources agreed upon. This also includes the delivery of constructive feedback during the development process, as well as moral and tangible support from upper management.

The strongest negative impacts to projects perceived by senior managers are grouped into three major subject areas: Insufficient and Unstable Resources, Poor Project Leadership, and Changing Requirements. The insufficient and unstable resources theme includes projects which experience a lack of sufficient staffing, budgets, and completion time. It also consists of project instability due to changes in resources during the project lifecycle, and intra-project competition for the same pool of personnel and financial resources. The poor project leadership theme highlights the project manager who may lack adequate leadership skills, lack sufficient interpersonal skills, or may also be ineffective at negotiating the dynamics of cross-functional teams. The changing requirements theme focuses on the instability of requirements as well as understanding the ramifications of requirements changes downstream in the product development process. It also includes the changing of strategic priorities by the organization.

The strongest positive impacts to projects perceived by project managers fall into four major subject areas: Team Quality and Commitment, Adequate and Stable Resources, Strong Customer Relationship, and Senior Management Commitment. The team quality and commitment theme was stated by an overwhelming majority of the project manager respondents. This theme included such aspects as: positive team member attitudes; team member excitement for the project; a well-qualified, synergistic team; strong technical competence; a hard-working team committed to completing the project despite having to face some obstacles and/or long work hours; and excellent team collaboration. The adequate and stable resources theme includes the provision of ample funding, staff, and schedule to start the project, as well as a stable resource environment throughout the duration of the project. The strong customer relationship theme emphasized strong interactions with product customers at all levels of engineering and customer participation during all phases of the project lifecycle. Customers clearly stating requirements, while proposing those which were realistic, was also an important consideration. Also suggested was the willingness by both the organization and the customer to be fully engaged with the project at the development site. Senior manager commitment was also recognized as a positive influence. Project managers felt that support by upper level management was essential to maintain critical staffing levels, and to reach agreement on the project's vision, goals, and level of priority.

The strongest negative impacts to projects perceived by project managers are grouped into three major subject areas: Insufficient and Unstable Resources, External Influences, and Changing Requirements. Aligned with the senior manager's views, the insufficient and unstable resources theme includes factors such as a lack of sufficient staffing, budgets, and completion time. It also includes a loss of key personnel to other projects, a deficiency in skills, excessive personnel changes, difficulty in hiring, unrealistic budgets and schedule, fluctuations in funding levels throughout the project lifecycle, and inadequate development tools. The external influences theme reflected project impacts due to public perceptions of failure, politics and policies, mandates from higher authorities, and delays due to spacecraft launch vehicle problems. The changing requirements theme highlighted continuous changes to project scope, requirements creep, the rapidity of changing requirements, and changes driven by the customer or by incomplete system concepts.

Types of Acceptable Project Managers

Senior managers were asked to determine the acceptable types of project managers (PM) to lead a complex system development that is dependent upon a significant number of emerging technologies. The question was posed because the situation often exists where the existing skills of the project managers available do not offer a perfect fit for the assignment. Thus, a critical management decision has to be made on the types of skills that senior managers would find acceptable for this assignment. Table 2 highlights the types of acceptable project managers and the corresponding results from the survey. The respondent was instructed to select *all of the choices that applied.*

Option	Types of Acceptable Project Managers	Frequency
A	Only a veteran PM who has numerous successes under his/her belt is appropriate for this position.	66.7 %
B	The PM is among the best and brightest employees in the organization. The PM learns everything quickly, but is still somewhat inexperienced at managing this type of endeavor.	61.9 %
C	The PM demonstrates sound personnel management skills but is not that strong technically. The PM relies mainly on others to make tough technical decisions.	33.3 %
D	The PM has substantial technical product development experience but has little or no real management experience.	14.3 %

Table 2. Senior Manager Views for Acceptable Project Managers

No one PM option was found to be checked 100% of the time. This could be due to the fact that every choice of PM realistically has both advantages and disadvantages. The dominant option was A, the veteran PM, with a two-thirds (66.7%) response rate. One-third of the respondents may have not selected the veteran PM for fear of this person being too conservative and set in their ways to think enough "out of the box." It is to be expected that novel approaches and innovations will be necessary for this type of project, in contrast to applying the same proven methodologies that have earned the PM their successes in the past. Option B came in a close second, selected 62% of the time, yielding a high vote of confidence from the senior manager population. This may result from the respect the PM has earned as being among the best and brightest, giving senior managers the impression that with the proper mentoring, this type of PM is likely to be very successful. With the ability to learn quickly carries the possibility that this type of PM will be up on the latest and greatest approaches available for the revolutionary challenge at hand.

Option C was selected one-third (33.3%) of the time, while option D was selected only 14% of the time. One possible interpretation of these response rates is as follows. Over 85% of the respondents did not select option D, the technical PM without sufficient management skills. This suggests that management skills are valued more than technical skills when confined to selecting between options C and D. This is confirmed by seeing that over double the response rate occurred for option C than option D. However, this finding defies two common management preparation theories. The first theory is that the best technical project managers were previously technical engineers that spent between 5 to 15 years becoming a well-respected technical authority through direct experience, and in the process were groomed by their superiors for future management roles. The second theory emanates from one interview respondent who suggested that an individual can learn the interpersonal aspect of the job quickly, but not the technical aspect. This is especially true for organizations that offer a plethora of short courses on leadership, communication, and the like. If one hasn't had sufficient experience building complex hardware and software, then it is likely they will not be effective at managing those that do.

Ideally, if an organization has the proper infrastructure to support the deficiencies of project managers, then all options to this question can be deemed acceptable. According to one interview respondent, the tendency is to select the veteran project manager if at all possible. However, regardless of experience, no project manager should operate in a vacuum. One can never become skilled enough to afford passing up the benefit derived from employee interactions.

Who Identifies & Classifies Project Risks

Project managers were surveyed to determine who actively participated in the identification and classification of risks to their project. Table 3 shows the percentage of projects which used a given type of employee to identify and classify risks. The table provides the results for both aggregate project data and by project type.

Employee Type	Project Type			
	Civil	Military	Commercial	Aggregated
Project Manager	88 %	100 %	64 %	86 %
Lead Systems Engineer	88 %	88 %	71 %	84 %
Lead Subsystem Engineers	73 %	63 %	57 %	67 %
Some Discipline Engineers	73 %	75 %	50 %	68 %
All Team Members	30 %	50 %	43 %	38 %
R&QA Personnel	58 %	50 %	29 %	49 %
Stakeholders	36 %	38 %	50 %	40 %
Senior Management	42 %	63 %	57 %	51 %
Scientists	45 %	19 %	0 %	29 %
Peer Review Board	48 %	38 %	21 %	40 %
External Review Board	3 %	0 %	0 %	1.6 %
Operations Personnel	3 %	0 %	0 %	1.6 %

Table 3. Percentages of Those Who Identify/Classify Risks by Type of Project

Those involved in risk identification and classification determine which risks are likely to affect the project, and then document the corresponding characteristics. They also evaluate each of the risks independently, and their interactions with other risks, sorting each into a collection of possible outcomes. Many risk management literature sources urge that risk identification and classification should not be a one-time event. Rather, it should be performed repeatedly throughout the project's duration.

Preferably, high percentages for each of the choices, nearing 100% for many of the employee types, should occur. However, only for the military projects was the project manager always actively participating in the process. The civil projects did not involve the project manager 14% of the time. The commercial projects only used the project manager 64% of the time. The lead systems engineer was relied upon more frequently by the government projects than the commercial projects. The military projects involved all team members the most, amounting to 50% of the projects. By comparison, the civil projects only utilized the entire project team 30% of the time. The Reliability and Quality Assurance (R&QA) group personnel were found to participate either at the 50% level or slightly above for the government projects, while at only 29% for the commercial projects. Stakeholders were used no more than 50% of the time by all three project sectors. Senior management was involved only 42% for civil projects, but ~60% for the military and commercial projects. The involvement of scientists by civil projects amounted to less than half of the time, by military projects less than 20% of the time, while commercial projects did not involve them at all. Less than 50% of any project type used peer review boards. Only one civil project cited the use of operations personnel.

Only one civil project cited the use of an external review board. Rechtin states that independent expert reviews give top management a feeling for the risk level of the decisions they are called on to make, by surfacing the major problem areas and prior decisions.[3] They serve as a safeguard against the human tendency to solve all problems at the lowest possible levels. Solving problems at the lowest levels may seem appropriate in the context of not needlessly bothering or alarming higher management levels, however senior management needs to know what the problems were and what at levels of risk they were solved. Not only may others view the associated risks from a different level of severity, a review of prior actions facilitates the opportunity to perform a better evaluation of total system risk.

Stakeholder, Operations Personnel, and Scientist Involvement

Project managers were asked to specify the level of involvement by key customers/stakeholders, operations personnel, and scientists for developing their complex system specifications. System specifications are intended here to mean the precise description of what the system has to do, by establishing the key technical parameters to bound the ranges of normal operation. Table 4 provides the results for the involvement of these employees by project type.

Personnel Type	Project Type			
	Civil	Military	Commercial	Aggregated
Key Customers/Stakeholders	75.0 %	62.5 %	64.3 %	69.3 %
Operations Personnel	63.6 %	56.3 %	57.2 %	60.4 %
Scientists	57.6 %	33.4 %	35.7 %	46.7 %

Table 4. Levels of Substantial Personnel Involvement for Developing System Specifications

From an aggregate perspective, over two-thirds (69%) of the projects used key customers/stakeholders substantially for developing system specifications. Inspecting by sector, the civil projects used key customers/stakeholders more than the military or commercial projects. This defies the expectation that the commercial sector would have mostly involved customers. Operations personnel were used an average of 60% for the projects, with the civil sector having the highest percentage (64%) of the three sectors. Scientists were used an average of just under 50% of the time, with the civil sector using them considerably more than the military or commercial arenas. Key customers/stakeholders were found to be used more than operations personnel or scientists by sector as well as by the aggregate group.

Frequent interactions with key personnel external to the core team are absolutely essential for project success. Many organizations have trouble with involving operators into the early project phases. Some of this may be due to management oversight for holistic, end-to-end involvement. This could also be partially caused by the project not yet at a stage that is exciting enough to stimulate the participation of these "hands-on" types. The lack of more scientists involvement cannot be readily explained. Operations personnel and scientists involvement was far lower in the civil and military sectors than is deemed essential. NASA reports specifically indicate the early project involvement by scientists and operations personnel in order to reinforce the "systems" perspective. From the civil sector data we conclude that this is not presently happening to sufficient levels. A greater focus must be placed upon involving these personnel types early in the project development cycle.

Making Technical Decisions

Project managers were asked to describe the method most often used to make technical trades for their project. Table 5 highlights the choices of methods and the corresponding survey results. The most common method for making technical trades was by inputs from the project manager, lead systems engineer, and several other lead personnel (60%). In contrast, only 3.2% of the time were technical decisions made solely by the project manager. Note that decisions by only the project manager occurred when the size of the project teams exceeded 100 members, there was a 25/75 split of company employees to contractors, and only some team member collocation was in effect. This tells us that under these circumstances, decision-making by a single individual may have been most prudent for project efficiency. Almost 15% of the projects used either a team consensus or a stakeholder review as their primary method for resolving tough technical decisions. The team consensus approach far outperformed the "reduced" version of team majority voting by over a factor of four. As team size increases, the effectiveness of achieving a consensus declines rapidly. This is confirmed by the data since project teams executing a consensus had a team size of less than 25 members. The stakeholder review approach indicates a strong relationship with the stakeholders, and either frequent communications or an unusually small number of tough technical decisions to make. By comparison, only one project used a peer review process. Note that this project team contained less than 10 members. One might postulate from this data that it is easier to assemble a group of stakeholders than organizational peers, even though this is intuitively unlikely. Either way, since a complex systems project is likely to have many tough technical tradeoffs to make, it doesn't appear prudent to implement a review process for every decision. Reviews are helpful to obtain objective perspectives when the timeliness of having to commit to a decision coincides with the date of the review. Two projects had their technical decisions imposed from a higher authority, which may indicate a lack of project manager empowerment, or strong political influences in action.

Technical Decision Method	Frequency
By inputs from the project manager, lead systems engineer, and several other lead personnel	59.7 %
By total team consensus	14.5 %
By stakeholder review	14.5 %
By team majority vote	3.2 %
By project manager decision	3.2 %
Imposed from a higher authority	3.2 %
By peer review	1.6 %

Table 5. Methods for Making Technical Decisions

Preparing the Organization for the Future

Senior managers were asked to describe what changes to their present organization were felt necessary to successfully manage the risks for developing the multi-disciplinary complex space systems of the future, e.g. the merging of life sciences with the physical sciences. The results appear in Table 6. The most popular response is to stress the return to the rigorous fundamentals of risk management early in a project lifecycle. Cross-disciplinary training is deemed a critical support mechanism to marry the fields of biology and molecular science with engineering. The increased use of automated tools was also identified. The expectations are to use computer simulation and modeling capabilities, and computer-based risk assessment tools, to the fullest extent possible. Such computer technology would aid in system design, selecting one architecture over another, and more accurately determining the levels of uncertainty for a given concept. More systems engineering involvement than traditional systems developments is also expected, emphasizing pure systems engineering approaches plus an increased number of qualified systems engineers working on the project.

Type of Organizational Change	Frequency
More Rigorous Risk Management Practices Early in the Project Lifecycle	27.2 %
Cross-Disciplinary Training	22.7 %
Greater Use of Automated Tools	18.2 %
More Systems Engineering Involvement	13.6 %

Table 6. Changes Needed for Developing Future Multi-Disciplinary Complex Systems

CONCLUSIONS

Managing requirements, human resource issues, technical system performance, and adequate budgets and schedules are all top concerns of senior managers. Human resource issues focused on project manager ability, sufficient staffing, and project team quality. Similarly, we observed that senior managers significantly emphasize strong leadership by the project manager as the greatest positive impact to a project, while project managers significantly emphasize the quality and commitment of their team. The requirement for strong project manager leadership is a recurring theme throughout the Air Force, NRO, DARPA, and NASA.[2] Project managers also place considerable importance on adequate and stable resources, and a strong customer relationship. Both senior managers and project managers agree that the strongest negative impact to a project is insufficient and unstable resources. The loss of key personnel is a contributing factor to this insufficiency, and has been a problem for the Air Force, the NRO, as for NASA in recent years. Both types of managers also identified changing requirements as another negative impact. Project managers emphatically cite external influences to be a strong negative impact to a project. On the contrary, senior managers failed to recognize external influences as a significant project risk. One of the most important roles a senior manager can play to help ensure the success of the organization's projects is to aid in filtering the disruption that external influences levy upon the project manager. The more that the project manager is freed up from such interferences, the more time is spent wisely on the technical coordination and evaluation of complex system development. Further, this increased focus on product development will increase the chances that the system will be developed right the first time.

Project managers cite senior manager commitment as a positive impact to a project. The stability of resources is certainly tied to this commitment. Smith and Reinertsen articulate that if top management echoes their support for a project to various parts of the organization, the lower levels of the hierarchy quickly get the message that the project is important.[4] Since senior managers may be unaware of the quality of their support to a project, obtaining critical feedback directly from the project manager on how they are doing may be necessary. Although senior managers feel that open, clear communications is critical for success, project managers do not cite this with equivalent vigor. This may be because from the project manager's position, it does not appear to be much of an issue. While wrapped up in the day-to-day operations of the system development process, shortfalls in communication may not be readily visible to the project manager. Smith and Reinertsen recommend the creation of robust communication channels by promoting contact at many levels of the organization. Every type of communication tool should also be utilized. Conrow suggests to use an electronic risk management database when practical.[1] Independent of the technology used, all risk analysis results should be clearly documented and communicated to the proper management individuals.

The type of acceptable project manager for leading a revolutionary complex system development is dependent upon the existing support infrastructure. Independent of such a support system, the most comforting choice by a senior manager is a veteran project manager with numerous past successes. A potential downside to this selection is that a seasoned veteran may be resistant to thinking "out of the box," and exhibit too strongly a risk-averse attitude. Another top choice is the inexperienced project manager who demonstrates the ability to learn quickly. Senior managers feel that with the proper mentoring in place, this type of leader will be quite successful. A key finding was that senior managers surprisingly valued sound management skills over strong technical skills for leading this type of project, when faced with having to choose between the two traits. This is contrary to the management model which slowly grooms star technical performers over 10-15 years before making them managers. It also suggests that the necessary technical skills can be picked up after becoming a manager, instead of vice-versa.

During the early phases of a project, risks are primarily identified by the project manager, the key project team members, the Reliability and Quality Assurance group, senior management, and in some cases the scientists and peer review boards. The data supports the need to emphasize more involvement by the entire project team, the stakeholders, the scientists, and the operations personnel. Mandatory training for technical project employees would help to raise the awareness as well as instruct how to approach identifying and classifying risks. Conrow states that in order for risk management to be effective, the team members must consider it as part of their daily decision-making process. Suitable incentives should be provided for those who identify potential project risks, to encourage this behavior. NASA also recommends the support of the R&QA group to provide guidance for risk identification and development of risk management plans. Hence, steps should be taken to promote continuous project team involvement with the R&QA group. Since the statistics show that only half of the projects made use of these support personnel, organizations may not be taking full advantage of their available risk management resources.

Projects used a considerable amount of customer/stakeholder involvement for developing project specifications. Key customers/stakeholders were found to be used more than operations personnel or scientists, both by the aggregate group as well as by project sector. Since organizations today recognize the need for the significant involvement of these types of personnel early in the development process, steps must be made to increase the percentage of involvement. NASA has specifically emphasized the need for operations personnel and scientists in all aspects of the project lifecycle. As a method for reducing project risk, management needs to rigorously support this cross-functionality from the team formation stage.

The most common method for making tough technical project decisions is by involving the project manager, the lead systems engineer, and several other project team leads. Two other popular methods were by total team consensus, and by stakeholder review. Team consensus was used for project teams totaling less than 25 members. Decisions made solely by the project manager occurred when the project team size exceeded 100 members, the team was dominated by support contractors, and the majority of the company team members were located in their functional organizations.

For organizations to prepare for successfully managing the risks associated with developing future multi-disciplinary complex space systems, a return to the rigorous fundamentals of risk management early in a project lifecycle was deemed the single most important step. Cross-disciplinary training was also cited as essential for marrying the disciplines of life science, physical science, and engineering. In the future, the extensive use of computer automated tools are expected to improve the risk management function by providing a more comprehensive and efficient means for identification, assessment, and mitigation studies. Sound systems engineering principles practiced by project teams that possess a higher number of systems engineers will be necessary to address the risks that are inherent with the challenges that lie ahead.

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